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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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RM2: rms Error Comparisons

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PREFACE

The work described in this report was performed by the Information Systems Division of the Jet Propulsion Laboratory.

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ABSTRACT

This paper uses the root mean square error performance measure to compare the relative performance of several widely known source coding algorithms with the RM2 image data compression system. The results demonstrate that RM2 has a uniformly significant performance advantage.

INTRODUCTION

An Advanced Imaging Communication System (AICS) is described in Ref. 1. Central to AICS is an adaptive image data compression algorithm called RM2, also described in Ref. 1. As noted, RM2 provides the user with broad flexibility to maximize his scientific information return. Virtually any compression factor may be selected on a frame by frame basis. More important, RM2 provides high rate/quality performance at all rates.

An independent "science value study" conducted by Cutts and Lebofsky [2] investigated comparisons of the rendition of morphological features by RM2 and a set of easily implemented spatial edit and interpolation algorithms. This study concluded that RM2 offers a factor of 4 to 6 improvement in information return.

The AICS channel coding provides a powerful and practical solution to the error vulnerability problem associated with the use of data compression. It is clear from Refs. 1 and 3-5 that the concatenation of Reed-Solomon block codes with Viterbi decoded convolutional codes assures that the potential gains of RM2 can be fully realized as an "end-to-end" advantage.

Although inferior in performance, the spatial edit algorithms do provide rate/quality tradeoffs which are very easy to implement. As such they are part of the Mariner Jupiter/Saturn 77 imaging system. Thus the above performance comparisons between the spatial edit algorithms and RM2 are quite useful. The purpose of this paper is to extend the RM2 performance comparisons to widely known source coding algorithms. Of the several standard criteria used for quantitative comparisons of image quality, we elect to use root mean square error (rmse).

RMS ERROR RESULTS

Source Picture

The monochrome source image we will use for comparisons is one of three selected by scientists to use in the science value study noted earlier [2].

The image is a 512 by 768 picture element (pixel) array derived from the Mariner 73 Mercury flybys. Quantization is at 8 bits/pixel. It contains both high detail and low detail areas in addition to a gradual shift in average brightness from one side to the other. Visual examples resulting from application of RM2 to this image can be found in Ref. 1.

Error Criterion

Letting x_{ij} be a picture element in the source image and \hat{x}_{ij} the same reconstructed picture element after decompression, rms error will be computed as

$$\text{rmse} = \sqrt{\frac{1}{N} \sum_{i,j} (x_{ij} - \hat{x}_{ij})^2} \quad (1)$$

where N is the total number of picture elements.

Algorithms

2DAH and 2DAF. The familiar Hadamard and Fourier transform techniques [6-8] were simulated in two-dimensional adaptive forms identified as 2DAH and 2DAF respectively. These same algorithms were used by Hilbert [9], [10] to provide comparisons with a new multi-spectral algorithm, CCA⁺.

The Hadamard transform approach involved taking the Hadamard transform of all 8 x 8 subsets of the image. The 64 coefficients were placed in 9 zones, each of which had the quantization and corresponding bit rate per coefficient based on the variance, or energy of the coefficients in the zone.

The Fourier transform technique was similarly adaptive; but in addition a symmetrical transform approach was used which doubly folded each data

⁺CCA is principally aimed at reducing future Landsat data volumes while at the same time drastically reducing ground processing requirements for automatic classification.

subset to provide horizontal and vertical symmetry. This symmetry reduces the intensity discontinuities at the boundaries due to the low pass filtering.

Since the adaptive bit allocation for both the Hadamard and Fourier transforms is performed in an "open loop" fashion the actual bits/picture used is a priori unknown. Thus these are not fixed-rate algorithms.

RHD. Chialin Wu provided a fixed rate algorithm for comparison by modifying the transform-dpcm systems in Ref. 8. In the latter systems, a one-dimensional transform is applied along a line followed by line to line dpcm coding of the resulting coefficients. Wu's modification flattens the distribution of energy in the transform domain. This leads to a simpler dpcm subsystem which in addition seems less susceptible to variations in data characteristics. The modification has worked best using the Hadamard transform which is performed here on blocks of 256 elements. The combined algorithm, to be treated in a later paper, will be called the RHD algorithm.

Graphical Results

The graphical results are shown in Fig. 1 where picture rate (in bits/pixel) is shown as the ordinate and rmse of Eq. 1, appears as the abscissa.

Selected rates for RM2 were 0.5, 0.66, 1.0, 1.33, 1.6 and 2.0 bits/pixel. Observe that in addition to these choices any arbitrary selection of data rate could be made. Such rate control is part of the algorithm^[1]. Thus the heavy line drawn between sample points in Fig. 1 is quite meaningful.

More typically for fixed rate algorithms, each optional rate requires some increase in complexity of the given algorithm. This is true of the RHD algorithm for which results are shown at 1.0, 1.6, 2.0, 2.33, and 2.66 bits/pixel. Similarly spatial edit algorithms were run at 1.0, 2.0, and 4.0 bits/pixel. Sample points are connected with dashed lines.

The two-dimensional adaptive Hadamard (2DAH) and Fourier (2DAF) algorithms were run at several different internal parameter settings which yielded several different average rates in bits/pixel. Such rates would be

data dependent and a priori unknown. The adaptive algorithms performed noticeably better than fixed rate non-adaptive versions (not shown). Sample points are shown connected by short dashed lines.

Conclusions

By the rmse performance measure, the graphs in Fig. 1 show that RM2 has a uniformly significant performance advantage over several other widely known source coding algorithms.

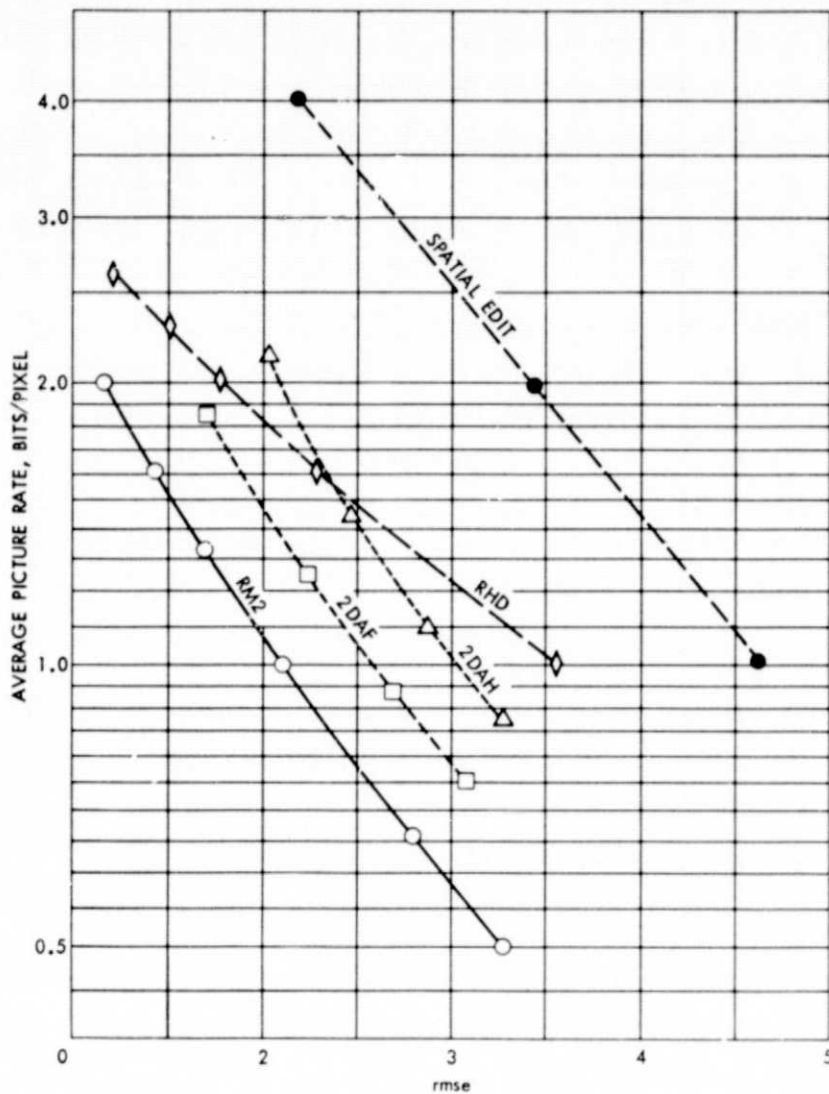


Fig. 1. Rate vs. rmse

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